optimizing the performances of PBO fibers so as to minimize their contribution to vulnerability of the pressure vessel to stress rupture had yet to be performed.

This work was done by Thomas K. DeLay of Marshall Space Flight Center and James E. Patterson and Michael A. Olson of HyPerComp Engineering, Inc.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy. a.nabors@nasa.gov. Refer to MFS-31838-1.

Making High-Tensile-Strength Amalgam Components

Instead of spheroids or flakes, wires are used as the solid constituents.

Marshall Space Flight Center, Alabama

Structural components made of amalgams can be made to have tensile strengths much greater than previously known to be possible. Amalgams, perhaps best known for their use in dental fillings, have several useful attributes, including room-temperature fabrication, corrosion resistance, dimensional stability, and high compressive strength. However, the range of applications of amalgams has been limited by their very small tensile strengths. Now, it has been discovered that the tensile strength of an amalgam depends critically on the sizes and shapes of the particles from which it is made and, consequently, the tensile strength can be greatly increased through suitable choice of the particles.

The term "amalgam" generally denotes an alloy of mercury with one or more other metals (e.g., copper or a copper alloy in the case of dental fillings). Amalgams can also be based on gallium, or gallium alloys, which melt near room temperature. An amalgam is formed by a peritectic reaction in a process called "trituration," in which the solid metal (e.g., copper) in powder form is ground together with the liquid metal (e.g., gallium). The grinding serves to break the oxide skin on the solid metal particles, enabling wetting of the clean metal surfaces by the liquid metal. The liquid metal reacts with the solid metal to form a new solid that is a composite of the starting solid metal (e.g., Cu) and an intermetallic compound (e.g., CuGa).

Heretofore, the powder particles used to make amalgams have been, variously, in the form of micron-sized spheroids or flakes. The tensile reinforcement contributed by the spheroids and flakes is minimal because fracture paths simply go around these particles. However, if spheroids or flakes are replaced by strands having greater lengths, then tensile reinforcement can be increased significantly. The feasibility of this concept was shown in an experiment in which electrical copper wires, serving as demonstration substitutes for copper powder particles, were triturated with gallium by use of a mortar and pestle and the resulting amalgam was compressed into a mold. The tensile strength of the amalgam specimen was then measured and found to be greater than 10^4 psi (greater than about 69 MPa).

Proceeding forward from this demonstration of feasibility, much remains to be done to optimize the properties of amalgams for various applications through suitable choice of starting constituents and modification of the trituration and molding processes. The choice of wire size and composition is expected to be especially important. Perusal of phase diagrams of metal mixtures could give insight that would enable choices of solid and liquid metal constituents. For example, phase diagrams have revealed that gallium should form amalgams with iron and nickel (as already demonstrated), as well as zirconium, and titanium. Finally, whereas heretofore, only binary alloys have been considered for amalgams, ternary additions to liquid or solid components should be considered as means to impart desired properties to amalgams.

This work was done by Richard Grugel of Marshall Space Flight Center.

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy. a.nabors@nasa.gov. Refer to MFS-32254-1.

Bonding by Hydroxide-Catalyzed Hydration and Dehydration

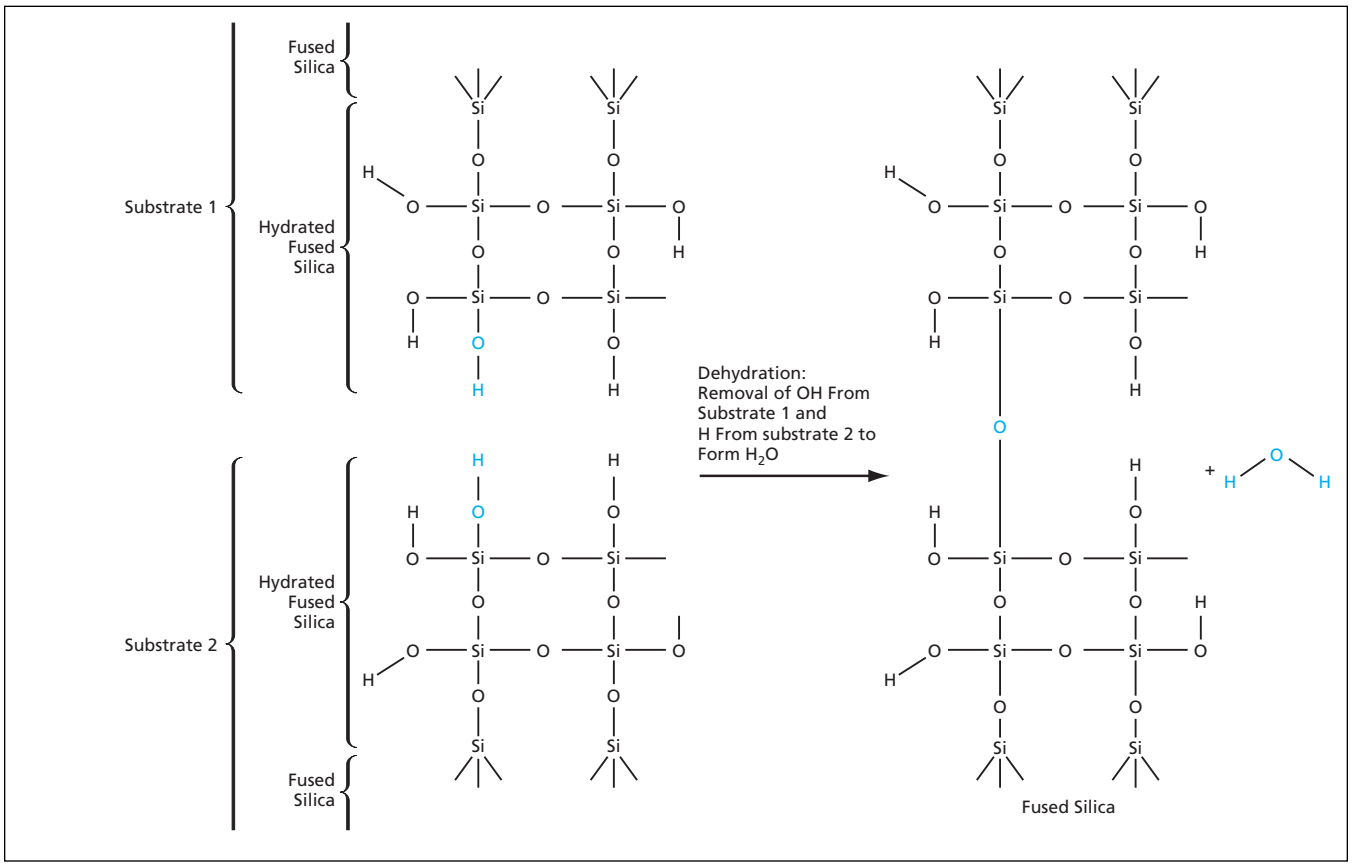
Room-temperature process can be varied to suit optical and non-optical applications.

Marshall Space Flight Center, Alabama

A simple, inexpensive method for bonding solid objects exploits hydroxide-catalyzed hydration and dehydration to form silicatelike networks in thin surface and interfacial layers between the objects. (Silicatelike networks are chemical-bond networks similar to, but looser than, those of bulk silica). The method can be practiced at room temperature or over a wide range of temperatures.

The method was developed especially to enable the formation of precise, reliable bonds between precise optical components. The bonds thus formed exhibit the precision and transparency of bonds formed by the conventional optical-contact method and the strength and reliability of high-temperature frit bonds. The method also lends itself to numerous non-optical applications in which there are requirements for precise bonds and/or requirements for bonds, whether precise or imprecise, that can reliably withstand severe environmental conditions. Categories of such non-optical applications include forming composite materials, coating substrates, forming laminate structures, and preparing objects of defined geometry and composition.

The method is applicable to materials that either (1) can form silicatelike networks in the sense that they have silicatelike molecular structures that are extensible into silicatelike networks or (2) can be chemically linked to silicatelike networks by means of hydroxide-



In a **Simple Example of Bonding** according to the present method, a silicon-oxygen-silicon bridge is formed by hydroxide-catalyzed dehydration between two fused-silica substrates, the mating surfaces of which have been hydrated. When a large number of such bridges form, the substrates are bonded together with great strength.

catalyzed hydration and dehydration. When hydrated, a material of either type features surface hydroxyl (— OH) groups. Examples of materials capable of forming silicatelike networks by means of hydroxide-catalyzed hydration and dehydration include several forms of silica (fused silica, fused quartz, and natural quartz), silica-based glasses, silicon having a thermally-grown surface oxide layer, and some other silica-based or silica-containing materials, including some laser crystals. Examples of materials that cannot form silicatelike networks but can be linked to them by means of hydroxide-catalyzed hydration and dehydration include some metals, oxides of some metals, and some non-silica-based, non-silica-containing laser crystals.

In this method, a silicatelike network that bonds two substrates (see figure) can be formed either by a bonding material alone or by the bonding material together with material from either or both of the substrates. In preparation for bonding, the mating surfaces of the substrates should be cleaned to render them maximally hydrophilic or at least minimally hydrophobic. Typically, an aqueous hydroxide bonding solution is dispensed and allowed to flow between the mating surfaces by capillary action. If at least one of the substrates can form a silicatelike network and if the surface figures of the substrates match with sufficient precision, then a suitable bonding solution would be one that contains a suitable concentration of hydroxide ions but substantially or completely lacks silicate material. If neither substrate material can form a silicatelike network through hydroxide catalysis or if the degree of mismatch between the surface figures of the substrates is such that silicatelike network cannot be formed at a sufficient rate, then a silicate material should be included in the bonding solution.

The solution acts to form a bond within a settling time, during the early part of which one can separate and/or move the substrates to align them more precisely. Regardless of whether substrates to be bonded are capable of forming silicatelike networks or have precisely matching surface figures, the settling time can be tailored via the concentrations of hydroxide ions and silicate material in the bonding solution. For example, for bonding silica-based materials, the settling time can be tailored between about 40 minutes at one extreme of composition (hydroxide but no silica) and tens of seconds at the other extreme of composition (silica with a smaller proportion of hydroxide).

If the surface figures of the substrates do not match precisely, bonding could be improved by including a filling material in the bonding solution. The filling material could be in the form of particles, foam, and/or a liquid. The filling material facilitates bridging of gaps between the substrate surfaces. Preferably, the filling material should include at least one ingredient that can be hydrated to have exposed hydroxyl groups and that can be chemically linked, by hydroxide catalysis, to a silicatelike network. The silicatelike network could be generated *in situ* from the filling material and/or substrate material, or could be originally present in the bonding material.

This work was done by Dz-Hung Gwo of Stanford University for Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32082.